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Teletraffic and Blocking Probability Estimation of OFDMA System

G.Sasibhushana Rao[a], Ch.Venkata Rao[b]*, K.Satya Prasad[b]

[a]*Dept. of Electronics and Communication Engineering, AU College of Engineering(A), Andhra University, Visakhapatnam, India,*
[b]*Dept. of Electronics and Communication Engineering, JNTU College of Engineering(A), JNTU, Kakinada, India, chalumurivr@gmail.com*

Abstract

In Wireless communication, to provide good Quality of service (QoS), network operators have to make the effective use of their available resources, which leads to effective network design and network planning. The blocking probability is the dominant parameter used for effective network design and network planning. It is defined as the probability of service being denied to users due to the non-availability of radio resources and is determined from the number of available channels and traffic load in Erlangs. In this paper, the blocking probability of Orthogonal Frequency Division Multiple Access (OFDMA) technique, used in 4G cellular communication system, is investigated for assessing the QoS of the network. The blocking probability of FDMA and TDMA based systems is estimated by using the Erlang-B formula. The blocking probability of OFDMA is estimated using a proposed dynamic algorithm which is based on the Signal to Interference plus Noise Ratio (SINR) of users and other QoS parameters such as the power transmitted by the base station to each sub-carrier and the data rate. The results obtained using the proposed algorithm show that when the traffic of the OFDMA system is increased from 2 to 40 Erlangs, then the blocking probability increases from 0.3378 to 0.7075. The variation in the blocking probability of an OFDMA-based cellular system with different data rates and base station-transmitted power to sub-carriers is also estimated.

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Keywords: Blocking probability; FDMA; TDMA; CDMA; OFDMA; 4G

* Corresponding author. Tel.: +91-9492784784
*E-mail address:*chalumurivr@gmail.com

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1. Introduction

CDMA and OFDMA are the multiple access techniques for the next generation wireless communication systems. Recently in 3G systems, Wideband Code Division Multiple Access (WCDMA) is used more than CDMA because it uses a wide bandwidth (5MHz) and provides more services than CDMA[1, 2, 3] and the received Walsh codes of WCDMA are orthogonal in the downlink transmission. But, in case of multipath propagation environment, this orthogonality property is destructed and results in inter-user and/or inter-symbol interference (ISI). To avoid this problem, a new multiple access technique, Orthogonal Frequency Division Multiple Access (OFDMA) is implemented for the LTE-downlink wireless communication (4G). Provision of high data rate transmission with efficiency for high band width, operation in multipath radio environment and efficient sharing of limited resources are the advantages of OFDMA system.

For any cellular communication system, the measure of its economic usefulness depends on the traffic (Erlang) that can be supported by the blocking probability[4]. Hence, the quality of service of any cellular system depends on the blocking probability estimation. In Global System for Mobile communications (GSM) and CDMA cellular systems, the blocking probability is determined by using the Erlang-B formula[4].

In this paper, the downlink blocking probability of OFDMA system is analysed by using a proposed dynamic new algorithm. The uplink blocking probability of OFDMA-based cellular networks is analysed in a recent study[5] but results exhibit high Peak to Average Power Ratio (PAPR). Hence, in this paper, SC-FDMA[6,7,8] scheme is considered instead of OFDMA.

2. Teletraffic Estimation of OFDMA-Based Cellular Communication Systems

In GSM, user is blocked if all the time or frequency channels are unavailable. In FDMA and TDMA based systems, the traffic channels are allocated to users as long as channels are available, after which all incoming users (traffic) are blocked until the channel becomes free. The blocking probability is obtained from the classical Erlang analysis of the M/M/S/S queue. The Erlang-B formula given below gives the blocking probability under the above conditions,

$$P_{blocking} = \frac{(\lambda/\mu)^S / S!}{\sum_{k=0}^{S} (\lambda/\mu)^k / k!} \tag{1}$$

where, S is the number of channels or servers, λ is the arrival rate of calls and μ is the holding time of calls.

In OFDMA system, the orthogonal subcarriers are distributed to each user according to their rate requirement and which depends on the Signal to Interference Ratio (SIR) experienced by users. Hence, the blocking probability analysis of traditional cellular systems like Global System for Mobile communications (GSM) cannot be applied to cellular OFDMA.

To calculate the blocking probability of OFDMA system, a cellular system with the following parameters is considered

- Cell radius 'R'
- A cluster with Cell 0 is the reference cell and cells 1 to 6 are its neighbors
- Call arrivals in each cell are Poisson distributed (with rate λ)
- Call holding times are exponentially distributed (with mean $1/\mu$)
- Rate requirement r_{req} bits/sec for all incoming calls
- Base station in each cell with N subcarriers available for allocation to mobile stations
- P_{tx} is the base station transmitted power to each subcarrier
- Log-normal shadowing (mean 'zero' and standard deviation σ) on each subcarrier
- 1:1 frequency reuse pattern

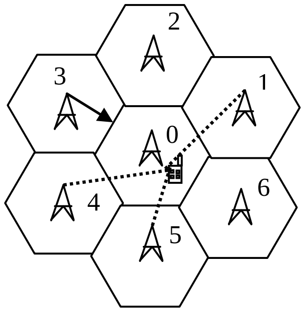

Fig.1. Interference from the neighboring BSs 1,4 and 5

2.1. Effect of Signal to Interference Noise Ratio

Consider a cellular network with mobile station ‘m’ and base station B_0 surrounded by N base stations. In downlink, the power received by mobile station ‘m’ is described by path-loss, shadowing effect and fast fading[9,10]. The power received by mobile station ‘m’ is

$$p_{j,m} = P_j k r_{j,m}^{-\eta} X_{j,m} Y_{j,m} \tag{2}$$

Path-loss model is characterized by the parameters k and η (where η>2. For urban environments it is between 3 and 4). The mean value of received power at a distance of $r_{j,m}$ from base station B_j is $P_j k r_{j,m}^{-\eta}$. The effect of shadowing is characterized by random variable $Y_{j,m}$ given by

$$Y_{j,m} = 10^{10^{\varepsilon_{j,m}}} \tag{3}$$

Where $\varepsilon_{j,m}$ is log normal random variable (with zero mean and standard deviation of 3-10 dB).
The fast fading effect is characterized by random variable $X_{j,m}$ with Rayleigh distribution of PDF given by

$$P_x(x) = e^{-x} \tag{4}$$

For simplicity, the above equation can be rewritten as

$$p_0 = P_0 k r_{0,m}^{-\eta} X_{0,m} Y_{0,\mu} \tag{5}$$

Interference power received by mobile station ‘m’ coming from all the other base stations of the network is expressed as:

$$p_{ext} = \sum_{j=1}^{N} P_j k r^{-\eta} X_j Y_j \tag{6}$$

The SINR at reference cell 0 is given by

$$\text{SINR}=\frac{P_0 k r^{-\eta} X_0 Y_0}{\sum_{j=1}^{N} P_j k r^{-\eta} X_j Y_j + N_0} \tag{7}$$

where N_0 is the thermal noise power

In urban environments, the thermal noise density is neglected in comparison to co-channel interference. Then SIR can be written as

$$\text{SIR}=\frac{P_0 k r^{-\eta} X_0 Y_0}{\sum_{j=1}^{N} P_j k r^{-\eta} X_j Y_j} \tag{8}$$

From the above analysis, the SINR of OFDMA downlink in the reference cell for i^{th} subcarrier can be rewritten as

$$\text{SINR}_i = \frac{P_{tx} d^{-\eta} 10^{\frac{\varepsilon}{10}}}{I_i + N_0}, 1 < i < N \tag{9}$$

where

P_{tx} is the power transmitted by base station on the i^{th} subcarrier,

d is radial distance between mobile station and base station,

η is the exponent of path-loss,

ε is the shadowing effect,

N_0 is the thermal noise density and

I_i is the interference received on i^{th} subcarrier.

Interference received on i^{th} subcarrier(Ii) is given by

$$I_i = \sum_{j=1}^{6} I_{i,j} l_A(i,j) = \sum_{j=1}^{6} P_{tx} d_j^{-\eta} 10^{\frac{\varepsilon_j}{10}} l_A(i,j) \tag{10}$$

$I_{i,j}$ is the interference from j^{th} neighboring cell (1≤j≤6).

d_j is the distance between MS in the reference cell and BS in the j^{th} neighboring cell

$l_A(i,j)$ = 1 when i^{th} subcarrier is allocated to mobile station of j^{th} neighboring cell.

= 0 otherwise

According to channel capacity theorem, data rate of OFDMA can be achieved by allocation of i^{th} subcarrier to mobile station (user) as $R = log_2(1 + SINR_i)$. Consider that a call has arrived in the reference cell. Then the base station allocates a set of subcarriers to mobile station. In this case

- Rate required by user is r_{req}
- Number of subcarriers required to user is n_r

From the above assumption, the incoming call is blocked if number of subcarriers available at base station is less than the number of subcarriers required to user (n_r) [11, 12].

The blocking condition is given by

$$\sum_{i=1}^{n_r} \log_2(1 + SINR_i) \geq r_{req} \tag{11}$$

To estimate the blocking probability, first we determine the distribution function of number of subcarriers required (n_r). The distribution function can then be determined from the following algorithm.

First, the initialization of OFDMA system parameters is done to estimate the cumulative distribution function of blocking probability with offered load using proposed algorithm and later, the carrier distribution is carried from the available set of subcarriers[13,14]. For each subcarrier allocation, the interference and simultaneous SINR is calculated. From this SINR, the data rate is calculated for every allocation of subcarriers (data rate $R = log_2(1 + SINR)$). This process is repeated till the total available set of subcarriers becomes empty. The calculated data rate is compared with the required data rate. From this comparison, the incoming call will be blocked and blocking probability is calculated.

2.2. Algorithm for Subcarrier Distribution

Where r_t is temporary rate required, n_{alt} is number of subcarriers allotted, S_{av} is set of subcarriers available, S_{alt} is number of subcarriers allotted and S_t is temporary set of subcarriers.

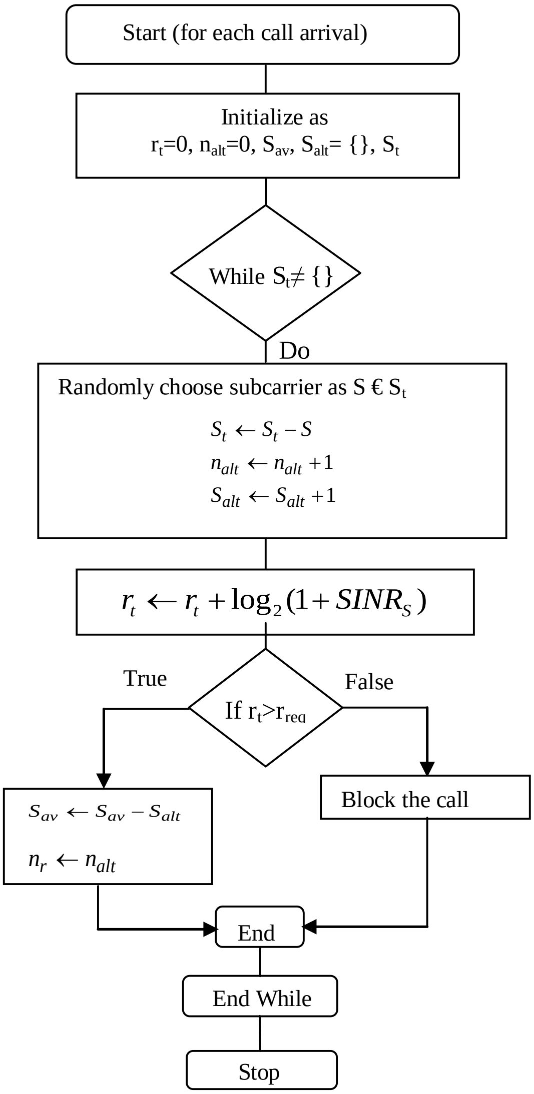

Fig.2. Algorithm for subcarrier distribution

3. Results And Discussions

Consider the conventional FDMA based Advanced Mobile Phone System (AMPS) with 30KHz channels, frequency reuse factor of 7 and the number of sectors in a cell is equal to 3.

Then the number of channels (servers) in 12.5MHz is calculated as

S = 12.5MHz/ ((30 KHz)*(7)*(3)) ≈ 20 channels/sector

From this, we estimate the FDMA based AMPS system's traffic (Erlang capacity) with blocking probability by using the Erlang-B formula.

Consider the conventional 3-slot TDMA based AMPS system with 30KHz channels, frequency reuse factor of 7 and the number of sectors in a cell is equal to 3. Then the number of channels (servers) in 12.5MHz is calculated as

S = 12.5MHz/((30KHz)*(7)*(3))* 3= 60channels/sector.

From this, we estimate the TDMA based AMPS system's traffic with blocking probability by using the Erlang-B formula. The variation of offered load with blocking probability for FDMA and TDMA based system is shown in Fig.3.

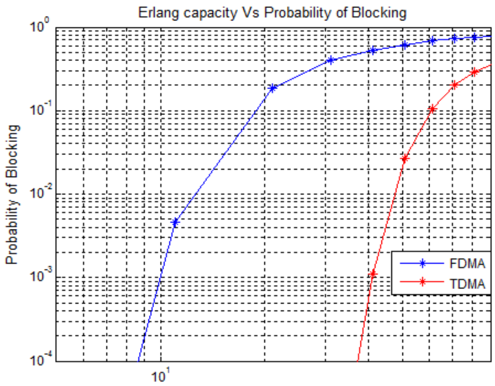

Fig.3. Blocking probability with traffic for FDMA and TDMA

To estimate the OFDMA cumulative distribution function of blocking probability with traffic, the parameters considered are

Total number of clusters = 7,

Rate required r_{req}= 20Kbps,

Number of subcarriers N = 512,

Power transmitted by base station per subcarrier P_{tx} = 10dBm,

Distance between the BS and MS (MS in the reference cell and BS in neighbour cell) d =1000m,

Path loss exponent η = 3.5,

Total number of users = 100,

Thermal noise level N_0 = -80dBm,

Shadowing on the BS-MS link ε is Gaussian with mean 0 and standard deviation σ, this value for every link is considered as any random value.

The variation of offered load with blocking probability for OFDMA is shown in Fig.4.

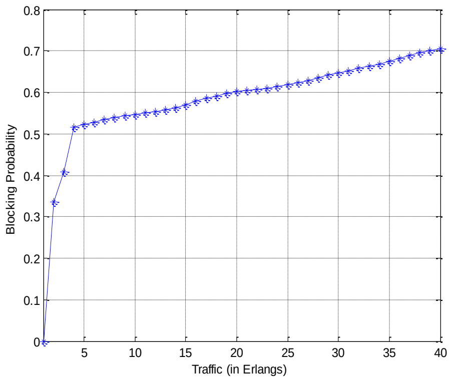

Fig.4. Cumulative distribution function of blocking probability

Table 1.Traffic Vs Blocking Probability.

Traffic [in Erlangs]	Blocking probability
2	0.3378
3	0.4095
5	0.5242
10	0.5552
15	0.5829
20	0.6170
25	0.6386
30	0.6521
35	0.6652
40	0.7075

It can be seen from Table 1, that if the traffic increases from 2 to 40 Erlangs, then the blocking probability of cellular OFDMA also increases from 0.3378 to 0.7075. In multi service applications, different data rates are used. For this purpose, the blocking probability of downlink cellular OFDMA is analyzed with different required data rates. The required data rates r_{req} are considered as 10Kbps, 15Kbps, 20Kbps and by this assumption, the blocking probability is evaluated using the proposed algorithm. In OFDMA system, the variation of blocking probability with offered load for different data rates is shown in Fig.5.

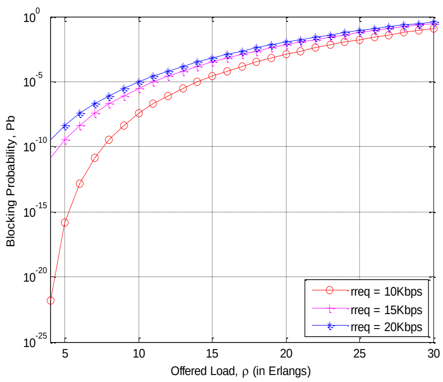

Fig.5. Variation of Blocking Probability with offered load (in Erlangs)

Table 2 presents the blocking probability vs offered traffic at different data rates. It can be seen that the blocking probability of cellular OFDMA increases with the increase of required data rate.

Table 2.Traffic Vs Blocking Probability with different Data Rates.

Traffic	Blocking probability		
[in Erlangs]	r_{req}=10 Kbps	r_{req}=15 Kbps	r_{req}=20 Kbps
5	$1.49x10^{-16}$	$3.66x10^{-10}$	$4.55x10^{-9}$
10	$3.52x10^{-8}$	$3.05x10^{-6}$	$9.46x10^{-6}$
15	$2.6x10^{-5}$	0.00031	0.0006
20	0.0012	0.00650	0.0107
25	0.0169	0.05850	0.0847
30	0.1205	0.30000	0.3946

The variation of blocking probability with offered load for different transmit powers is shown in Fig.6. It can be observed from Fig. 6 that the block probability is higher at lower transmit powers.

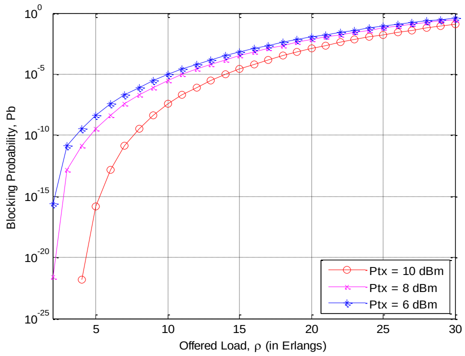

Fig.6. Variation of Blocking Probability with offered load (in Erlangs)

4. Conclusions

The accurate estimation of blocking probability plays a major role in the design of cellular communication systems (from 1G to 4G). Blocking probability is the key parameter in all cellular systems for assessing their network's QoS. OFDMA blocking probability is estimated by an efficient algorithm which depends on the distribution of sub carriers and other parameters used for transmission. If the teletraffic of OFDMA based cellular system increases from 2 to 40 Erlangs then the blocking probability increases from 0.3378 to 0.7075. For 30 Erlangs of offered load, as the required data rate changes from 10Kbps to 20Kbps, then the blocking probability changes from 0.1205 to 0.3946. The blocking probability of cellular OFDMA is increased with the increase of data rates. This can be minimized only by employing higher transmit power.

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